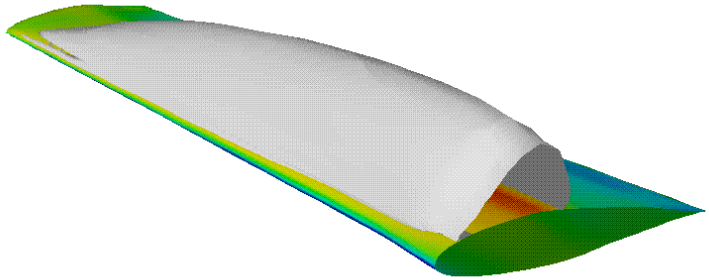
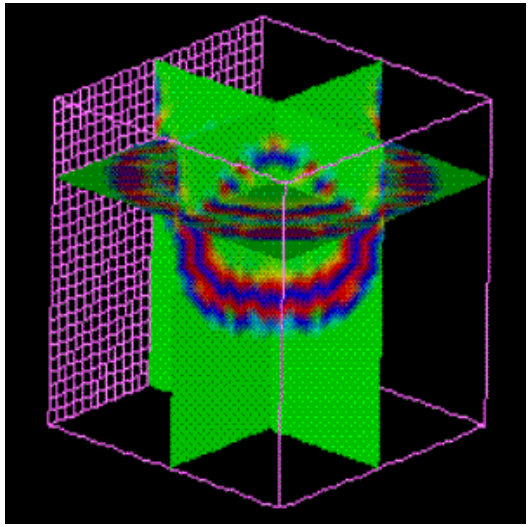
CUMULVS Tutorial



ACTS Collection Workshop

Dr. James Arthur Kohl
Computer Science and Mathematics Division
Oak Ridge National Laboratory



August 7, 2003

Research sponsored by the Applied Mathematical Sciences Research Program, Office of Mathematical, Information, and Computer Sciences, U.S. Department of Energy, under contract No. DE-AC05-00OR22725 with UT-Battelle, LLC.

Scientific Simulation Issues…

- Fundamental Parallel Programming
  → Synchronization, Coordination & ***Control***
- Distributed Data Organization
  → Locality, Latency Hiding, ***Data Movement***
- Long-Running Simulation Experiments
  → ***Monitoring***, ***Fault Recovery***
- Massive Amounts of Data / Information
  → Archival Storage, ***Visualization***
- Too Much Computer, Not Enough Science!
  → ***Need Some Help…***

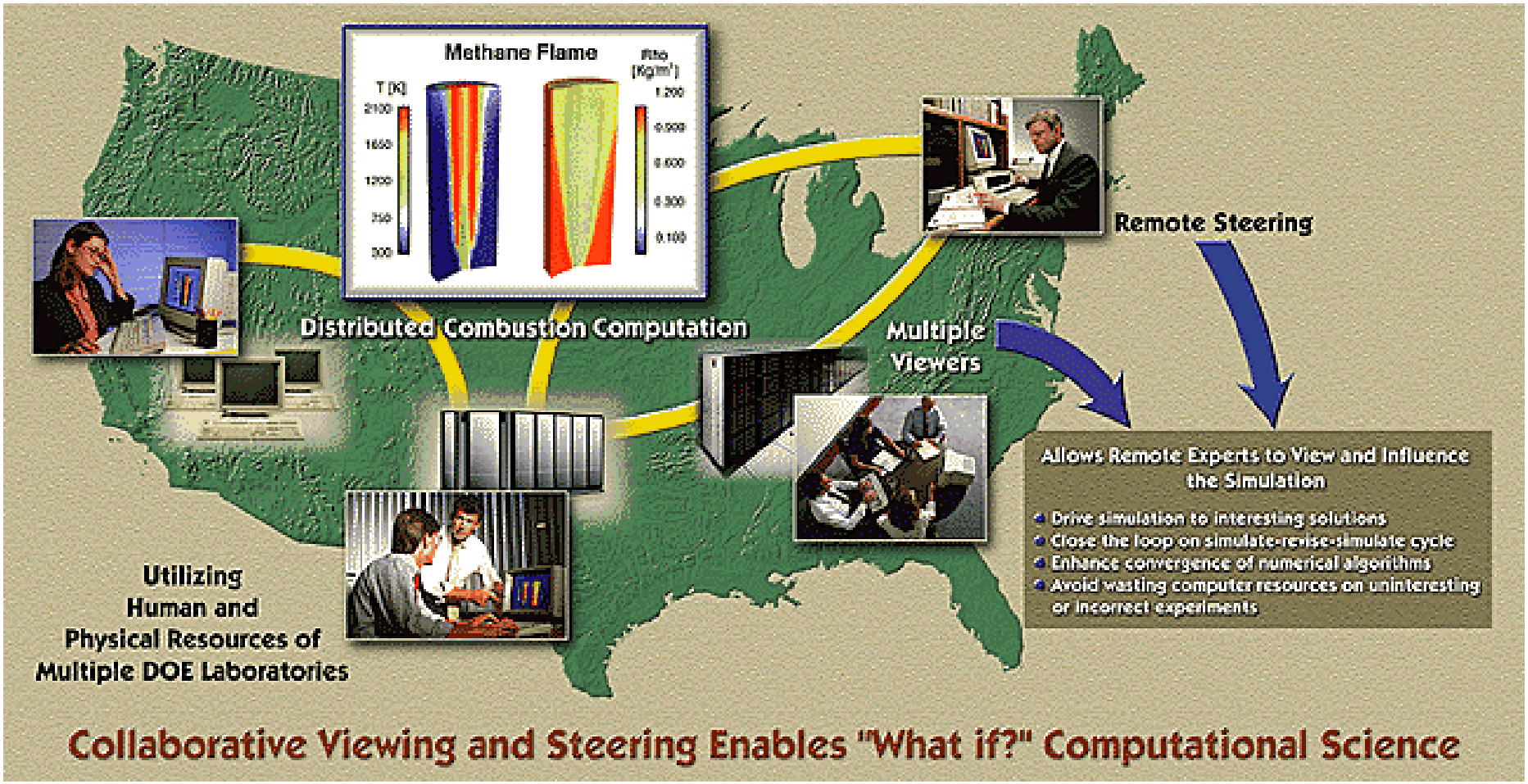
Potential Benefits from Computer Science Infrastructure:

- **On-The-Fly Visualization**
  - ⇒ Interactive Access to Intermediate Results
  - ⇒ Attached as Needed, Minimize Overhead
- **Computational Steering**
  - ⇒ Apply Visual Feedback to Alter Course / Restart
  - ⇒ "Close Loop" on Experimentation Cycle
- **Fault Tolerance**
  - ⇒ Automatic Fault Recovery / Load Balancing
  - ⇒ Keep Long-Running Simulations Running Long

(Collaborative, User Migration, User Library for Visualization and Steering)

- Collaborative Infrastructure for Interacting with Scientific Simulations:
  - ⇒ Run-Time Visualization by Multiple Viewers
    - → Dynamic Attachment, Independent Views
  - ⇒ Coordinated Computational Steering
    - → Model & Algorithm Parameters
  - ⇒ Heterogeneous Checkpointing / Fault Tolerance
    - → Automatic Fault Recovery and Task Migration
  - ⇒ Coupled Models…

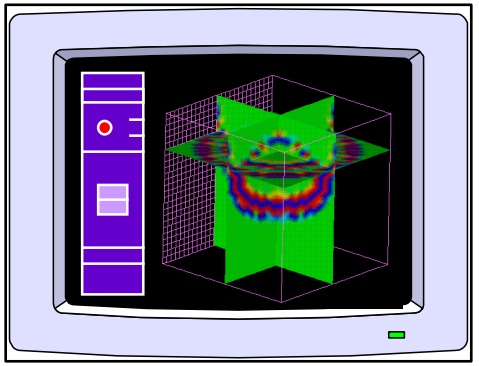
Collaborative Combustion Simulation



CUMULVS Visualization Features

⇒ **Interactive Visualization**

* Simple API for Scientific Visualization
* Use Your Favorite Visualization Tool



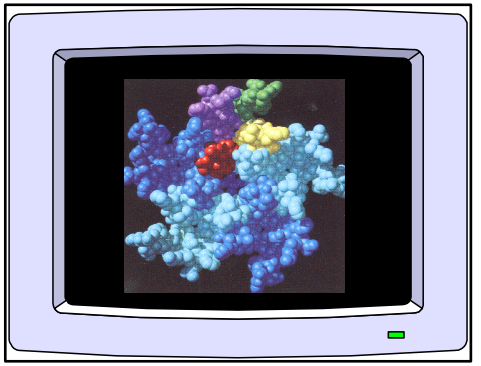
⇒ **Minimize Overhead When No Viewers**

* One Message Probe, No Application Penalty

⇒ **Send Only Viewed Data**

* Partial Array / Lower Resolution

⇒ **Rect Mesh & Particle Data**

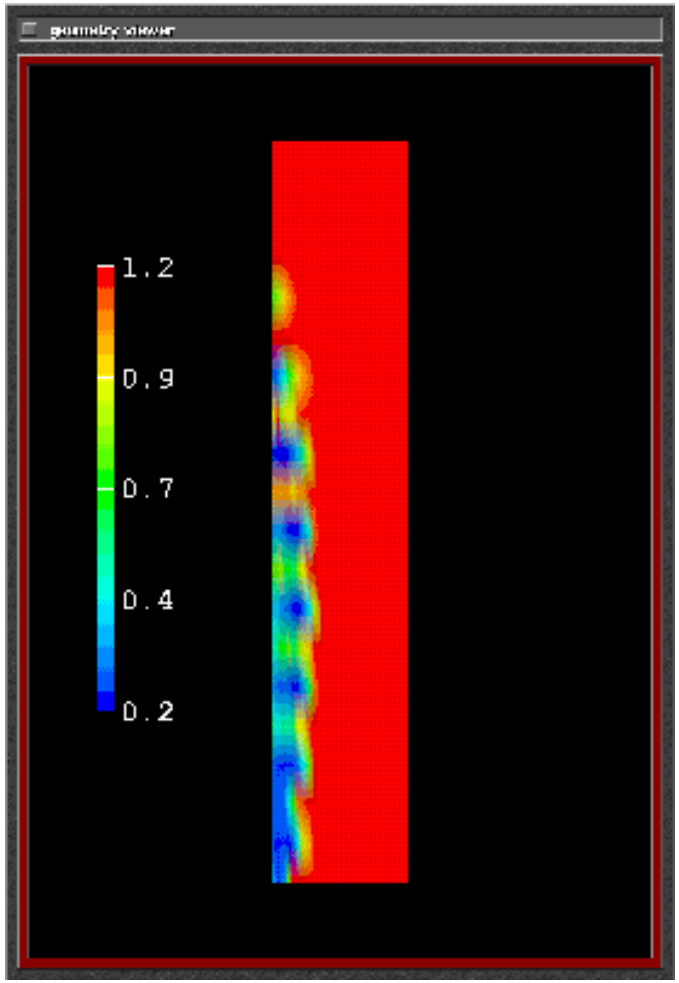


⇒ **Common (HPF) Data Distributions**

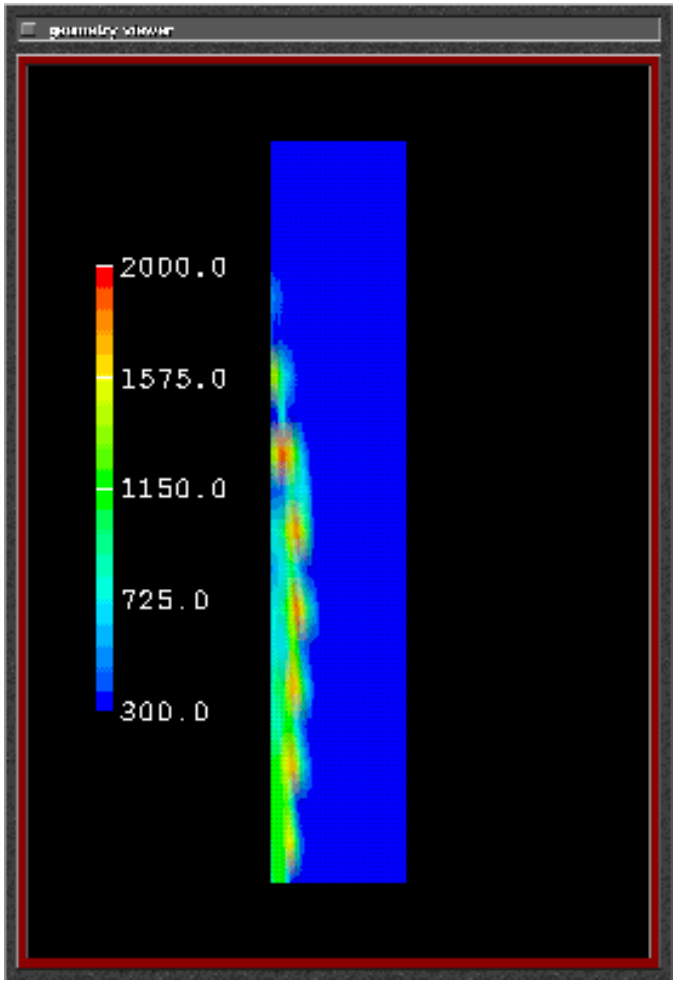
* BLOCK, CYCLIC, EXPLICIT, COLLAPSE

⇒ **Soon Unstructured, Sparse & Adaptive Meshes…**

Multiple Simultaneous Views

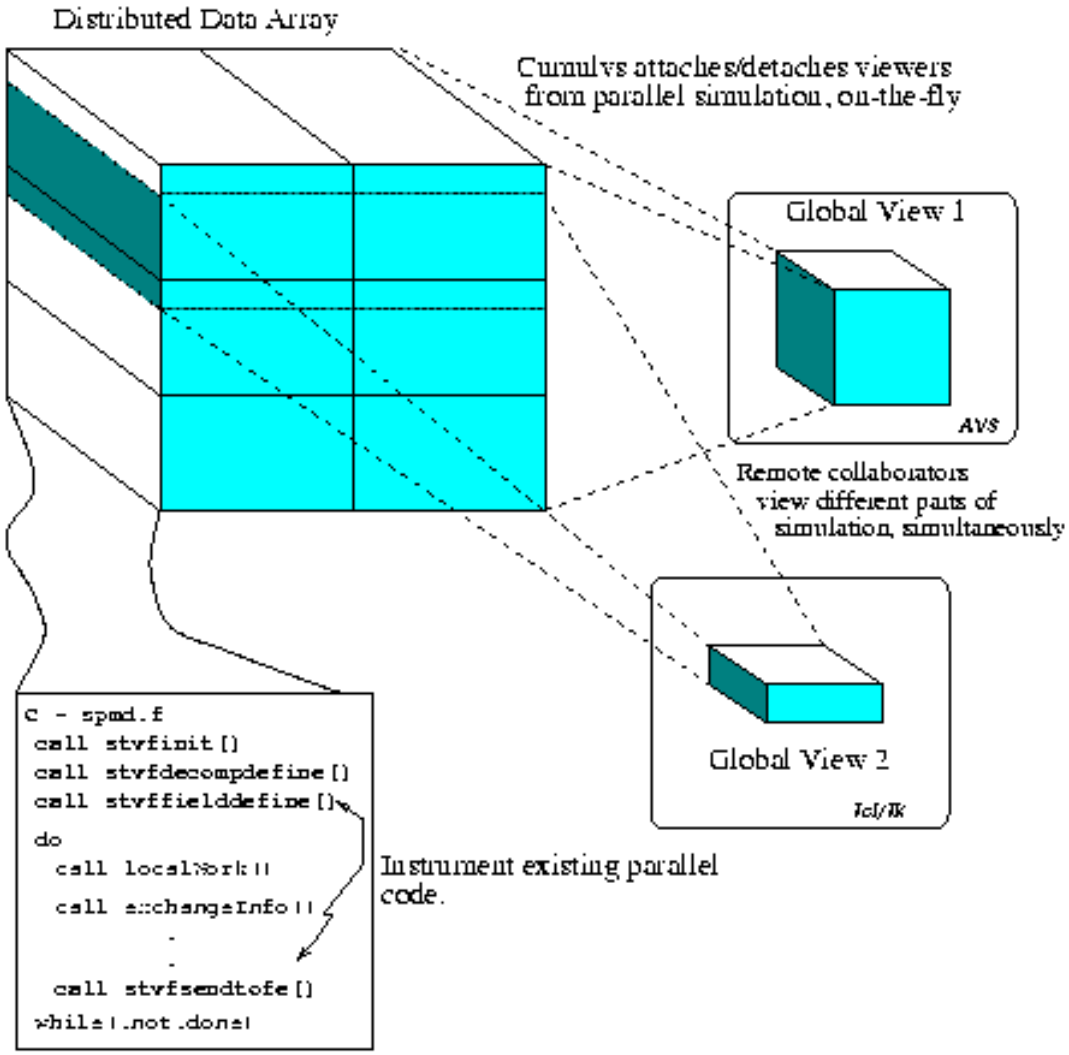


Density



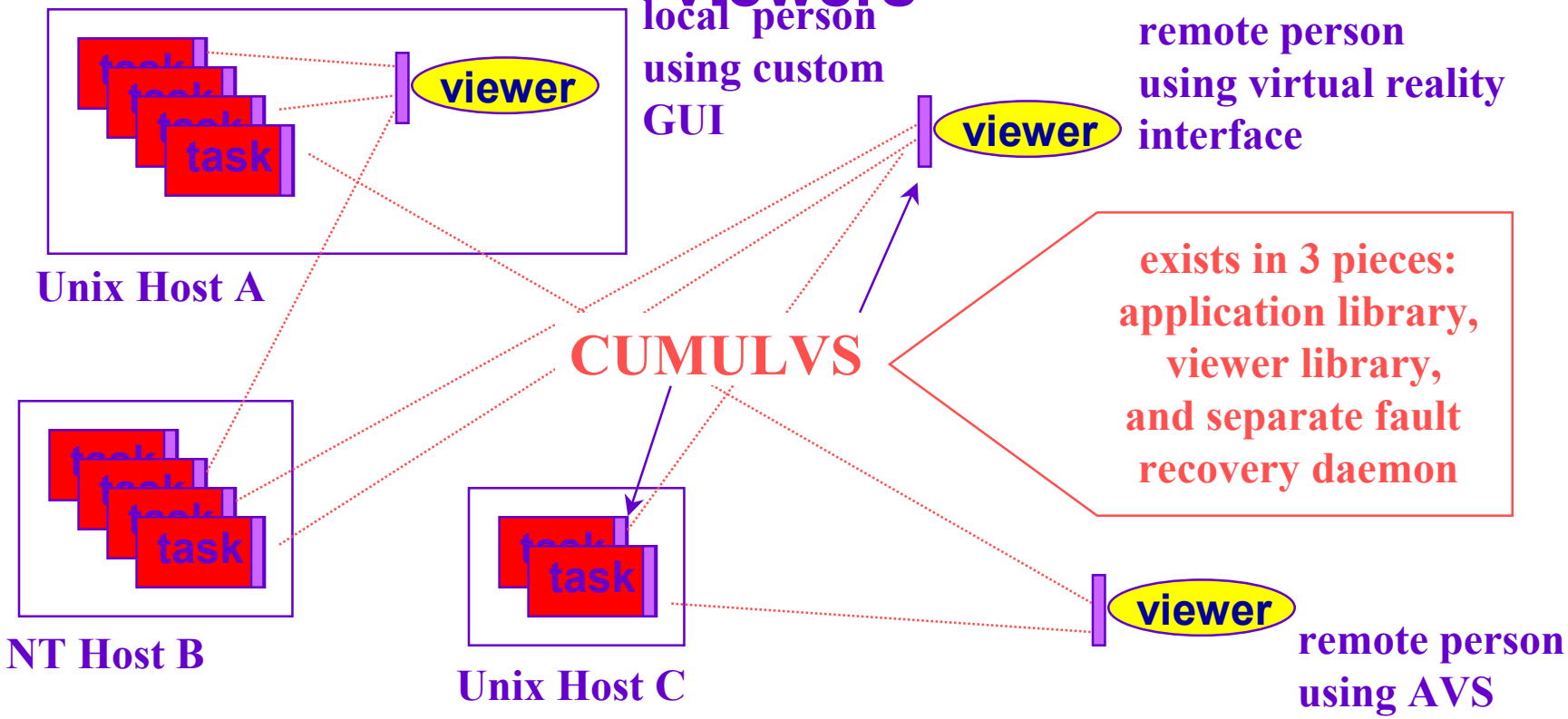
Temperature

Multiple Distinct Views



CUMULVS Architecture

coordinate the consistent collection and dissemination of information to / from parallel tasks to multiple viewers



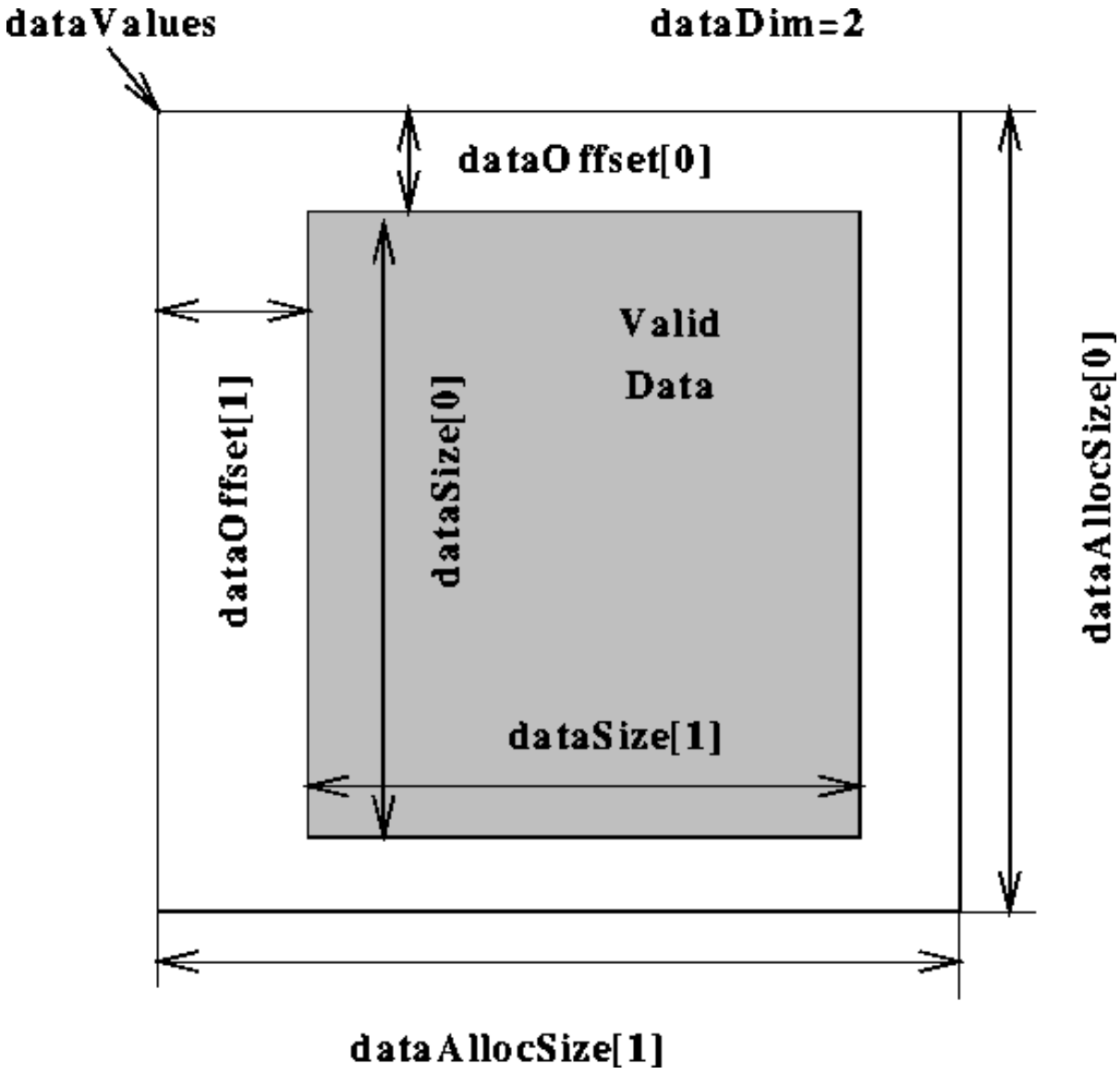
interact with distributed / parallel application or simulation

supports most target platforms (PVM / MPI, Unix / NT, etc.)

Instrumenting Programs for CUMULVS

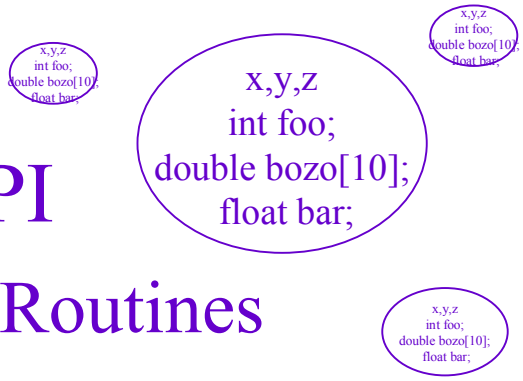
- CUMULVS Initialization ~ One Call (Each Task)
  - ⇒ Logical Application Name, # of Tasks
- Data Fields (Visualization & Checkpointing)
  - ⇒ Local Allocation: Name, Type, Size, Offsets
  - ⇒ Data Distribution: Dim, Decomp, PE Topology
- Steering Parameters
  - ⇒ Logical Name, Data Type, Data Pointer
- Periodic CUMULVS Handler
  - ⇒ Pass Control for Transparent Access / Processing
- Typically 10s of Lines of Code…

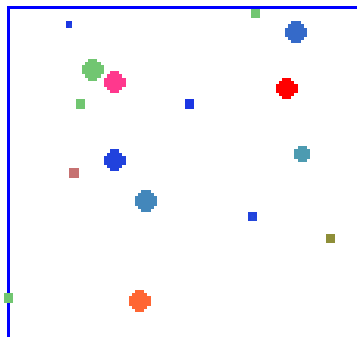
Local Allocation Organization



CUMULVS Particle Handling

- Particle Data Fundamentally Different
  - ⇒ Data Fields Encapsulated in a Particle Container
  - ⇒ Explicit Coordinates Per Particle
- Particle-Based Decomposition API
  - ⇒ User-Defined, Vectored Accessor Routines
- Viewing Particle Data
  - ⇒ AVS Module Extensions
  - ⇒ Tcl/Tk Slicer Particle Mode





CUMULVS
Steering Features

- **Computational Steering**

  ⇒ API for Interactive Application Control

- **Modify Parameters While (Long) Running**

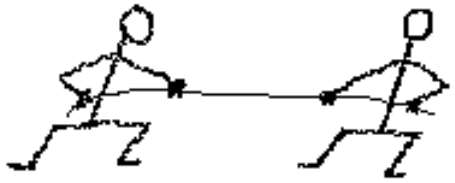
  * Eliminate Wasteful Cycles of Ill-Posed Simulation
  * Drive Simulation to More Interesting Solutions
  * Enhance Convergence of Numerical Algorithms

- **Allows "What If" Explorations**

  * Closes Loop of Standard Simulation Cycle
  * Explore Non-Physical Effects…

Coordinated Steering

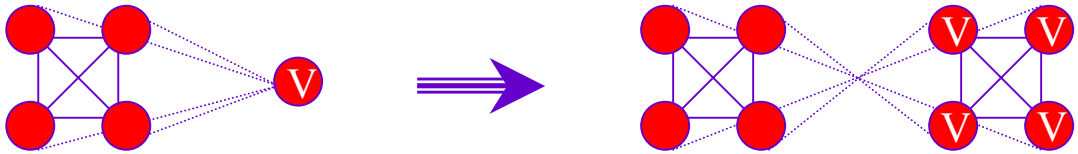
- Multiple, Remote Collaborators
- Simultaneously Steer Different Parameters
  - ⇒ Physical Parameters of Simulation
  - ⇒ Algorithmic Parameters ~ e.g. Convergence Rate
- Cooperate with Collaborators
  - ⇒ Parameter Locking Prevent Conflicts
  - ⇒ Vectored Parameters…
- Parallel / Distributed Simulations
  - ⇒ Synchronize with Parallel Tasks
  - ⇒ All Tasks Update Parameter in Unison



Parallel Model Coupling in CUMULVS

- Natural Extension to CUMULVS Viewer Scenario

  ⇒ Promote "Many-to-1" → "Many-to-Many"



- Translate Disparate Data Decompositions

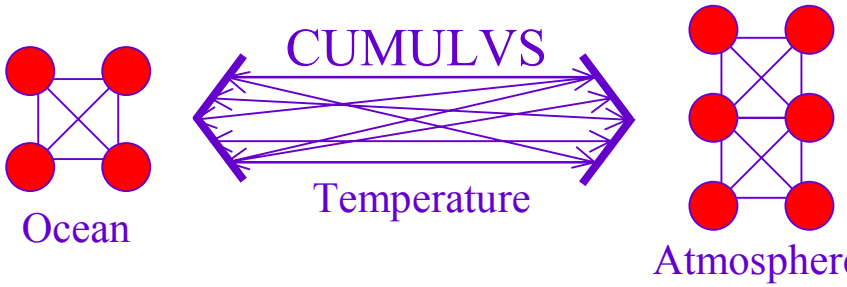
  ⇒ Parallel Data Redistribution Among Shared Data Fields

  → `stv_couple_fields( fieldID, appname, fieldname, ... );`

  ⇒ Fundamental Model Coupling Capability

  → Next Step ~ Interpolation in Space & Time, Units Conversion…

E.g. Regional Climate Assessment

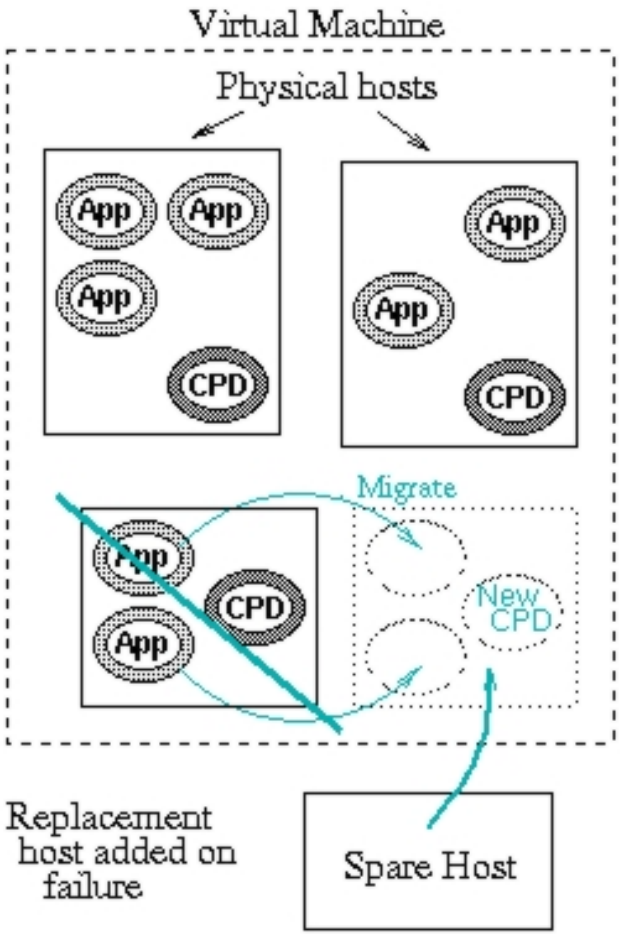


CUMULVS Fault Tolerance Features

- **Application Fault Tolerance**
  - ⇒ Automatic Detection and Recovery from Failures
- **User Directed Checkpointing**
  - ⇒ User Decides What / Where to Checkpoint
  - ⇒ Minimizes Amount of Stored Data
- **Heterogeneous Task Migration**
  - ⇒ Restart Tasks on Heterogeneous Hosts
  - ⇒ Restart is Automatically *Repartitioned* if Host Pool is of Different Size or Topology (Yikes!)
- **Avoids Synchronizing Distributed Tasks**
  - ⇒ Asynchronous Checkpoint Collection and Fault Detection
  - ⇒ Minimize Intrusion of Checkpoint / Restart

Run-Time Fault Monitor

- One Checkpointing Daemon (CPD) Per Host
  - ⇒ Ckpt Collector / Provider
  - ⇒ Run-Time Monitor
  - ⇒ Console for Restart / Migrate
- CPDs Comprise Fault-Tolerant Application…
  - ⇒ Handle Failure of Host / CPD
  - ⇒ Coordinate Redundancy
  - ⇒ Ring Topology



Rollback Versus Restart…

- Rollback Recovery:
  - ⇒ Only Replace Failed Tasks, "Roll Back" the Rest
  - ⇒ Elegant & Cool, But You Must…
    - → Monitor ALL Communication for Restart Notification
    - → Unroll Program Stack, Reset Comm & File Pointers…
  - ⇒ Necessary for High Overhead Restart Cases
- Restart Recovery:
  - ⇒ "Genocide" ~ Kill Everything & Restart All Tasks
  - ⇒ Simple Approach, No Additional Instrumentation
  - ⇒ Not as Efficient a Recovery in All Cases…

Checkpoint Data Collection

- Data from Each Local Task Collected/Committed
  - → `stv_checkpoint();`
- Invoke When Parallel Data / State "Consistent"…
  - ⇒ Highly Non-Trivial in General! (Chandy/Lamport)
  - ⇒ Straightforward for Most Iterative Applications
    - → Save Checkpoint at Beginning or End of Main Loop
- No Automatic Capturing of Other Internal State:
  - ⇒ Open Files, I/O, Messages-in-Transit…
  - ⇒ CUMULVS Assumes User Handles This Recovery
    - → Can Be Done Manually Using Saved Checkpoint State
    - → Future Extensions to Assist…

Manual Software Instrumentation

- SPDT 98 Case Study ~ SW Instrumentation Cost

Instrumentation:	Seismic:	Wing Flow:
Original Lines of Code	20,632	2,250
Vis / Steer System Init	3	3
Vis / Steer Variable Decls	48	73
CP Restart Initialization	21	12
CP Rollback Handling	41	34
Total Instrumentation	204 ~ 1.0 %	188 ~ 7.7 %

Checkpointing Efficiency

- SPDT 98 Case Study ~ Execution Overhead

Seconds per Iteration

Experiment:	SGI:	Cluster:	Hetero:
Seismic - No Checkpointing	2.83	6.23	9.46
Seismic - Checkpoint for Restart	2.99	6.50	10.76
Seismic - Checkpoint for Rollback	3.03	6.66	10.90
Wing - No Checkpointing	0.69	1.58	6.14
Wing - Checkpoint for Restart	0.77	1.71	7.10
Wing - Checkpoint for Rollback	0.79	1.71	7.30

(Checkpointing Every 20 Iterations ~ every 15 sec to 4 mins…!)

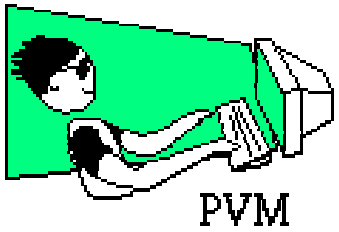
Seismic Overhead: 4-14% Restart, +1-3% Rollback.
Wing Overhead: 8-15% Restart, +0-2.5% Rollback.

An Aside: PVM vs. MPI

- Comparison of Features and Philosophy
- Which One to Choose?

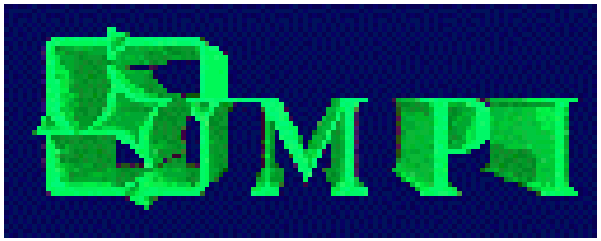
  $\Rightarrow$ Both Useful for Given Application Needs…
- CUMULVS Issues

  $\Rightarrow$ Internals and General Usage



PVM (Parallel Virtual Machine)

- Use Arbitrary Collection of Networked Computers as a Single, Large Parallel Computer
  - ⇒ Workstations, PCs (Unix or NT) ~ Clusters
  - ⇒ SMPs, MPPs
- Programming Model & Runtime System
  - ⇒ Message-Passing ~ Point-to-Point, Context, Some Collective Operations, Message Handlers
  - ⇒ Resource & Process Control, Message Mailbox, Dynamic Groups, Application Discovery
  - ⇒ Fault Notification



Message Passing Interface Standard

- Library Specification for Message-Passing
  - ⇒ Designed By Broad Committee of Vendors, Implementors and Users
  - ⇒ High Performance on Massively Parallel Machines and Workstation Clusters
- Comprehensive Message-Passing System
  - ⇒ Point-to-Point, Collective, One-Sided
  - ⇒ Groups/Communicators, Topology, Profiling, I/O
  - ⇒ Some Process Control (MPI-2 ~ MPI_SPAWN)

PVM vs. MPI: Different Goals

- MPI
  - ⇒ Stable Standard, Portable Code
  - ⇒ High Performance on Homogeneous Systems
- PVM
  - ⇒ Research Tool, Robust, Interoperable
  - ⇒ Good Performance on Heterogeneous Systems

PVM vs. MPI: Different Philosophies

- MPI
  - ⇒ Static Model (~ MPI_SPAWN in MPI-2…)
  - ⇒ "Rich" API (MPI-1 / 128, MPI-2 / 288)
  - ⇒ Performance, Performance, Performance…
- PVM
  - ⇒ Dynamic Model
  - ⇒ "Simple" API (PVM 3.4 / 75)
  - ⇒ Flexibility (& Performance)

Portability vs. Interoperability

- Portable:
  - ⇒ Re-compile Source Without Modification on a Different System, with C, C++, Fortran Support
  - ⇒ True of Both MPI and PVM.
- Interoperable:
  - ⇒ Executables on Different Systems Communicate
  - ⇒ PVM ~ Yes, MPI ~ Sometimes (Not Required)
  - ⇒ Different MPI Implementations? IMPI ~ Soon…
  - ⇒ Language Interoperability?
    - → PVM ~ Yes, IMPI ~ Soon…

Performance vs. Flexibility

- To Be Flexible, You Must Pay the Price…
- Heterogeneity Overheads:

  ⇒ Data Conversion, Network Protocol Selection,
  Extra Message Headers (on top of Native Comm)…
- Choose the Lowest Common Denominator?

  ⇒ Not the Best on Any System.
- Performance Dictates Locally Optimal Solution.

  ⇒ Lose Interoperability…

Interesting Result

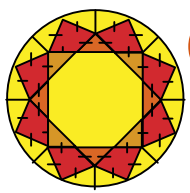
- You can build an MPI implementation that supports interoperability and system dynamics across different systems / languages (some already do ~ Mpich, LAM, IMPI…).

- But, given all these conditions:

  $\Rightarrow$ It Would Perform About the Same as PVM!!

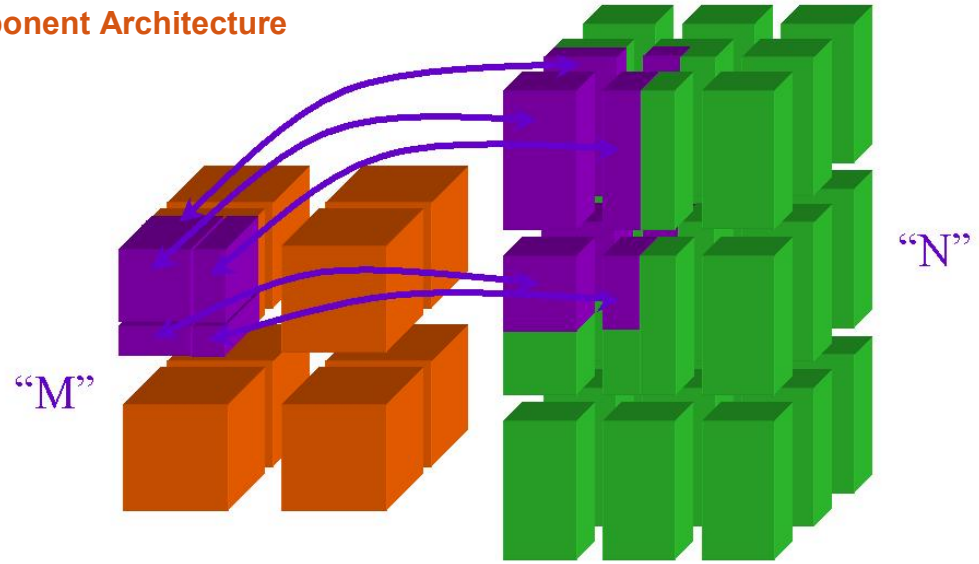
Supporting MPI Applications in CUMULVS

- CUMULVS Works with MPI Applications! ☺
- But MPI Doesn't Have Everything We Need (Internally)
  - ⇒ Static Model, Minimal Operating Environment
  - ⇒ No Name Service / Database, Fault Recovery / Notification?
  - ⇒ MPI_SPAWN( )…? Proxy Server for Viewer Attachment?
- Existing CUMULVS Solution:
  - ⇒ Applications Communicate Using MPI or PVM or ???
  - ⇒ CUMULVS Viewers / CPDs Still Attach Using PVM
- Possible "Reduced-Functionality" MPI Version…?
  - ⇒ Currently Under Development…



CCA
Common Component Architecture

Future CUMULVS Plans (1 of 3)



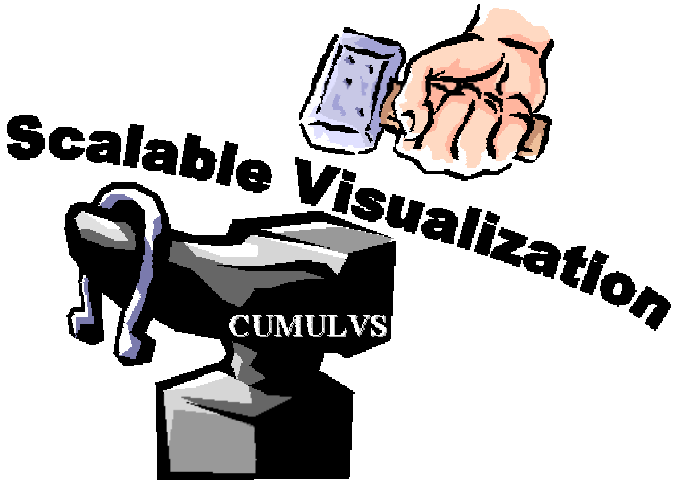
- CCA "MxN" Parallel Data Redistribution
  - ⇒ Builds on CUMULVS Viz & Coupling Protocols
  - ⇒ CUMULVS & PAWS (LANL) Being Integrated
    - → "MxN" Generalizes Capabilities of Both Systems
      - * Point-to-Point versus Persistent Connections (a la Viz)
    - → CUMULVS Complements PAWS Coupling Work

Future CUMULVS Plans (2 of 3)

CUMULVS as a Foundry to Forge New Technology

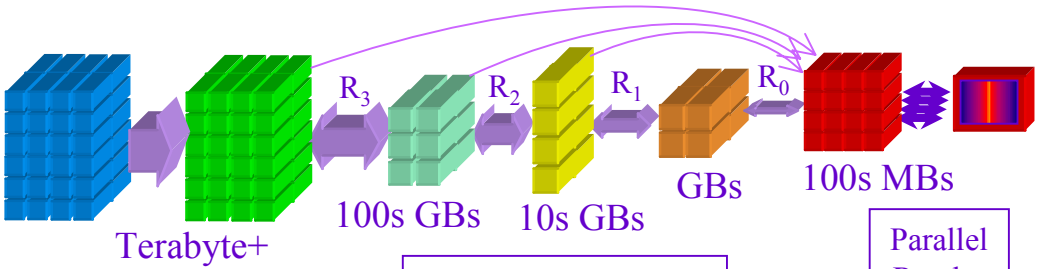
High-Performance Visualization

- **Full Parallel Integration** of Pipeline
- CCA "MxN" → "M x N x P x Q x R"!

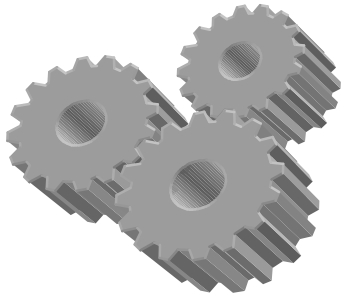


Proposed "Fully Connected" User-Centric Simulation Cycle

Scalable Visualization Cache Architecture



Future CUMULVS Plans (3 of 3)
Feature Extensions…



- Application Interface:
  - ⇒ Assist Manual Instrumentation of Applications
    - → GUI, Pre-Compiler...
- Checkpointing Efficiency:
  - ⇒ Tasks Write Data in Parallel / Parallel File System?
  - ⇒ Redundancy Levels, Improve Scalability…
- Portability:
  - ⇒ Other Messaging Substrates
    - → Reduced Functionality / Direct Connect for CCA & MPI

CUMULVS Summary

- Interact with Scientific Simulations
  - ⇒ Dynamically Attach Multiple Visualization Front-Ends
  - ⇒ Steer Model & Algorithm Parameters On-The-Fly
  - ⇒ Automatic Heterogeneous Fault Recovery & Migration
- Future Opportunities
  - ⇒ Couple Disparate Simulation Models
  - ⇒ Integrate as "MxN" Component in CCA
  - ⇒ Application Instrumentation GUI / Pre-Compiler

http://www.csm.ornl.gov/cs/cumulvs.html

Seismic Example ~ 2D (Tcl/Tk)

Seismic Example ~ 3D (AVS)

Air Flow Over Wing Example ~ 3D (AVS)